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(54) LOW STRAIN TYPE CARBURIZED AND QUENCHED STEEL STOCK FOR GEAR

(57)Abstract:
PROBLEM TO BE SOLVED: To determine the chemical composition of a steel stock for gear, minimal in strain.
SOLUTION: A steel stock, having a composition which consists of, by weight, 0.10-0.35% C, 0.50-2.5% Si, 0.20-2.50% Mn, 0.01-2.50% Cr, 0.01-0.70% Mo, 0.01-2.0% Ni, and the balance iron with inevitable impurities and in which Ac3, represented by equation, $Ac3=920-203\sqrt{C}+44.7Si+31.5Mo-30Mn-11Cr+40Al-15.2Ni+13.1W+104V+40Ti$, is regulated to 850-960° C and also DI, represented by equation, $DI=7.95\sqrt{C}(1+0.70Si)(1+3.3Mn)(1+2.16Cr)(1+3.0Mo)(1+0.36Ni)(1+5.0V)$, is regulated to 30-250mm, is used. This steel stock is carburized at 850-1,000° C, hardened at 800-950° C, and tempered, by which the noncarburized zone of the steel stock is provided with dual-phase structure consisting of martensite containing 10-70area% ferrite. Further, one or more kinds selected from

the group consisting of 0.01–0.70% W and 0.01–1.0% V and/or the group consisting of 0.005–2.0% Al, 0.005–1.0% Ti, 0.005–0.50% Nb, and 0.005–0.50% Zr are added. It is desirable to regulate DI to 30–150mm.

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(54) [Title of the invention] LOW STRAIN TYPE CARBURIZED and QUENCHED STEEL STOCK FOR GEAR

(57) [Abstract]

[Problem to be solved] To determine the chemical composition of a steel stock for gear, minimal in strain.

[Solution] A steel stock, having a composition which consists of, by weight, 0.10 -0.35% C, 0.50-2.5% Si, 0.20-2.50% Mn, 0.01-2.50% Cr, 0.01-0.70% Mo, 0.01-2.0% Ni, and the balance iron with inevitable impurities and in which Ac_3, represented by equation (1),

Ac_3=920-203vC+44.7Si+31.5Mo-30Mn-11Cr+40Al-15.2Ni+13.1W+104V+40Ti (1),

is regulated to 850-960°C and also D_I, represented by equation (2)

D_I=7.95vC(1+0.70Si)(1+3.3Mn)(1+2.16Cr)(1+3.0Mo)(1+0.36Ni)(1+5.0V) (2),

is regulated to 30-250mm, is used. This steel stock is carburized at 850-1,000°C, hardened at 800-950°C, and tempered, by which the noncarburized zone of the steel stock is provided with duel-phase structure consisting of martensite containing 10-70area% ferrite. Further, one or more kinds selected from the group consisting of 0.01-0.70% W and 0.01-1.0% V and/or the group consisting of 0.005-2.0% Al, 0.005-1.0% Ti, 0.005-0.50% Nb, and 0.005-0.50% Zr are added. It is desirable to regulate D_I to 30-150mm.

[Effect] A carburized and quenched strain becomes 1.0% or smaller, and it becomes unnecessary to correct a tooth form, and a cost is reduced.

[Claims]

[Claim 1] A low strain type carburized and quenched steeling stock for a gear, having a chemical composition which consists of:

carbon (C): 0.10-0.35wt.%,
silicon (Si): 0.50-2.5wt.%,
manganese (Mn): 0.20-2.50wt.%,
chromium (Cr): 0.01-2.50wt.%,
molybdenum (Mo): 0.01-0.70wt.%, and
nickel (Ni): 0.01-2.0wt.%,
the balance: iron with inevitable impurities,

wherein an Ac_3 point parameter calculated by the following (1) equation:

Ac_3=920-203√C+44.7Si+31.5Mo-30Mn-11Cr+40Al-15.2Ni+13.1W+104V+40Ti (1) is in a range of 850-960°C,

an ideal critical diameter (D_I) calculated by the following (2) equation:

D_I=7.95√C(1+0.70Si)(1+3.3Mn)(1+2.16Cr)(1+3.0Mo)(1+0.36Ni)(1+5.0V) (2) is in a range of 30-250mm,

wherein the steel stock is carburized at a temperature in a range of 850-1000°C, hardened at a temperature in a rage of 800-950°C, and tempered, and a structure of a non-carburized part of the thus obtained steel stock is a dual-phase structure consisting of martensite containing 10-70area% ferrite.

[Claim 2] The low strain type carburized and quenched steel stock for a gear according to claim 1, which further contains at least one element selected from the group consist of the following chemical component composition:

tungsten (W): 0.01-0.70wt.% and

vanadium (V): 0.01-1.0wt.%.

[Claim 3] The low strain type carburized and quenched steel stock for a gear according to claim 1, which further contains at least one element selected from the group consisting of the following chemical component composition:

aluminum (Al): 0.005-2.0wt.%,

titanium (Ti): 0.005-1.0wt.%,

niobium (Nb): 0.005-0.50wt.%, and

zirconium (Zr): 0.005-0.50wt.%

[Claim 4] The low strain type carburized and quenched steel stock for a gear according to claim 1, which further contains at least one element selected from the group consisting of the following chemical component composition:

tungsten (W): 0.01-0.70wt.%, and

vanadium (V): 0.01-1.0wt.%, as well as

at least one element selected from the group consisting of the following chemical component composition:

aluminum (Al): 0.005-2.0wt.%,

titanium (Ti): 0.005-1.0wt.%,

niobium (Nb): 0.005-0.50wt.%, and

zirconium (Zr): 0.005-0.50wt.%.

[Claim 5] The low strain type carburized and quenched steel stock for a gear according to any one of claim 1 to claim 4, wherein the ideal critical diameter (D_I) is in a range of 30 to 150mm.

[Detailed explanation of the invention]

[0001]

[Technical field to which the invention belongs] The present invention relates to a low strain type carburized and quenched steel stock for a gear, having an extremely small strain amount at carburization and quenching, which is suitable, for example, as a steel stock for a gear of an automobile, a construction machine, an industrial machine and the like.

[0002]

[Prior art] For example, in recent automobiles, calmness at driving is remarkably improved, nevertheless a noise is produced at driving. This is mainly due to a gear noise generated from a gear. A gear noise is generated by inconvenience of gear engagement, and such the inconvenience of gear engagement is generated as a result of a strain when a gear half-finished product molded into a prescribed shape is subjected to treatment of carburization and quenching or carburization and nitriding and quenching (hereinafter, collectively referred to as carburization and quenching) in order to harden a surface thereof.

[0003] That is, since a transformation stress due to production of martensite, that is, a stress due to volume expansion produced at transformation from an austenite structure to a martensite structure is generated at carburization and quenching of a steel stock for a gear, generation of a strain in a steel stock cannot be avoided and, as a result, since a dimensional precision of a gear cannot be maintained high, a gear noise is generated. In particular, in a gear for transmission of an automobile, although there is extremely strict restriction on a noise, since a shape is small, and a wall thickness is small, and since a structure in an interior of a gear is a structure mainly composed of martensite partially containing bainite, a strain is easily produced at carburization and quenching, and this is a great cause for generating a gear noise.

[0004] Then, in order to improve a dimensional precision of a gear, there is a method of

performing tooth form correcting treatment for reducing a quenching strain amount by subjecting a carburized and quenched gear half-finished product to mechanical cutting procession to partially remove a carburized layer. However, in such the tooth form correction by mechanical cutting, since not only productivity is considerably reduced due to increase in manufacturing steps, and a manufacturing cost is considerably increased due to mechanical cutting procession, but also a dispersion is produced in a surface hardness and a residual stress, there is a problem also from a viewpoint of quality.

[0005] From the aforementioned points, a steel stock for a gear is used in many cases without subjecting to tooth form correcting treatment after carburization and quenching and, therefore, in order to improve a dimensional precision of a carburized and quenched gear half-finished product, decrease in a quenching strain is demanded. Such the carburization and quenching strain amount is greatly influenced by quenching property of a steel stock. Further, since carburization and quenching is usually performed at a high temperature of about 920°C, enlargement of an austenite crystal particle during carburization is one of causes for strain generation. Further, recently, in order to shorten a carburization time to improve productivity, a method of raising a carburization temperature and, accompanying this, also raising a quenching temperature has been tried.

[0006] A method of decreasing a quenching strain amount of a steel stock for a gear, has been previously studied variously. For example, a method of suppressing quenching property low by controlling a chemical component composition of a steel stock in a particular narrow range so that quenching property becomes a lower limit of a Jominy band is known. In addition, Japanese Patent Application Laid-Open (JP-A) No.4-247848 and JP-A No.59-123743 disclose a method of adjusting a crystal particle fine by adding an appropriate amount of a crystal particle miniaturizing element such as Al, Ti, Nb and the like to a steel in order to suppress enlargement of a crystal particle during carburization and temperature retention (hereinafter, referred to as prior art 1).

[0007] In addition, JP-A No. 5-70925 discloses a method of subjecting a gear half-finished product consisting of a steel in which a chemical component composition such as Si, Mn, Cr, Mo and V is limited to a particular range, to carburization and nitriding treatment, cooling this to a temperature region of a Ar_1 transformation point or

lower of a tooth surface part, that is, a carburized and nitrided part (hereinafter, the same), retaining this in a temperature range of not lower than a Ar_3 transformation point of a tooth surface part and not higher than a Ar_1 transformation point of an interior of a tooth, that is, a non-carburized part (hereinafter, the same), thereby, converting an interior of a tooth into fine ferrite・pearlite while maintaining a tooth surface part in the austenite state, then, performing quenching and tempering, thereby, converting a carburized and nitrided part of a tooth surface part into martensite, and maintaining an interior of a tooth which has already finished transformation as non-quenched ferrite and fine pearlite (hereinafter, referred to as prior art 2). Fig.4 shows a schematic perspective explaining an interior of a tooth of a gear, a tooth surface part and a gear core part.

[0008] In addition, for example, JP-A No. 3-260048 discloses a method of reducing a heat treating strain by nitriding treatment which is performed at a low temperature, tufftriding, gas nitriding, and gas soft-nitriding (hereinafter, referred to as prior art 3).

[0009]

[Problems to be solved by the invention] However, the aforementioned each prior art has the following problems. The prior art 1 has an advantage that since enlargement of a crystal particle during carburization and temperature retention can be suppressed by adjusting a crystal particle fine, a dispersion of a quenching strain in an interior of a tooth can be decreased, and a quenching strain can be uniformized. However, the prior art 1 has a limitation for suppressing generation of a strain accompanied with martensite transformation, and has a problem that a strain cannot be sufficiently reduced.

[0010] The prior art 2 has an advantage that a quenching strain due to volume expansion accompanied with martensite generation can be reduced by converting an interior of a tooth into a ferrite・pearlite structure. However, the prior art 2 has a problem that since an interior of a tooth, that is, a non-carburized part is a ferrite・pearlite structure, it is difficult to maintain sufficient toughness, and since a heat treating temperature must be strictly managed, heat treating operation becomes complicated, not only inhibiting productivity, but also increasing a cost.

[0011] The prior art 3 has an advantage that since a hard nitrogen compound layer can be formed on a surface, a surface hardened layer having better abrasion resistance can

be obtained and, since treatment is performed at a low temperature region of 500-700°C, deformation of a treated part is small. However, the prior art 3 has a defect that since a hardened layer depth is shallow and, in order to obtain a sufficient hardened layer, a long time of 50 to 100 hours of nitriding treatment is necessary, not only productivity is inhibited, but also a cost is increased.

[0012] Accordingly, an object of the present invention is to solve the aforementioned problems, and provide a low strain type carburized and quenched steel for a gear in which an amount of generation of a strain after conventional effective carburization treatment, and quenching and tempering treatment is extremely small, therefore, a gear having a high dimensional precision is obtained and, as a result, a gear for an automobile, a construction machine, an industrial machine and the like generating no gear noise upon use can be easily and effectively thermally treated, and can be economically manufactured.

[0013]

[Means to solve the problems] In order to solve the aforementioned problems, the present inventors intensively studied and, as a result, obtained the following findings.

[0014] Since a main factor influencing a carburization and quenching strain amount of a steel stock for a gear is a strain due to volume expansion produced when an austenite structure is transformed into a martensite structure, the present inventors found out that a quenching strain amount is dramatically reduced by the presence of 10-70% of ferrite in an austenite structure at heating before quenching, and converting a structure after carburization and quenching into a ferrite·martensite dual-phase structure.

[0015] In the present invention, provision of a steel stock which can manufacture a gear under the easy and economical heat treatment condition of carburization and quenching is also one of important goals. Moreover, a steel stock of the present invention has essential requirement that the steel stock becomes to have a structure in which ferrite is present in a martensite structure, by carburization and quenching. Therefore, it is necessary that a Ac_3 transformation temperature of a steel stock of the present invention is higher than a normal carburization and quenching temperature region.

[0016] Then, the preset inventors studied influence of an element such as Si, Mn, Cr, Mo, Al, V and the like in a steel on a Ac_3 transformation temperature in detail and, as a

result, found out that since by limiting contents of these elements appropriately, a ferrite·martensite dual-phase structure is easily obtained even under the conventional carburization condition and, by adding an appropriate amount of a ferrite reinforcing element, an interior of a tooth, that is, a non-carburized part is strengthened and a fatigue strength of a tooth surface part is improved, a quenching strain amount can be dramatically reduced without reducing a fatigue strength of a dedendum.

[0017] The present invention was completed based on the aforementioned findings, and the low strain type carburized and quenched steel stock for a gear of the invention described in claim 1 is characterized in that the steel stock has a chemical component composition of C: 0.10-0.35wt.%, Si:0.50-2.5wt.%, Mn:0.20-2.50wt.%, Cr:0.01-2.50wt.%, Mo: 0.01-0.70wt.%, and Ni: 0.01-2.0wt.%, and the balance : iron with inevitable impurities, wherein an Ac_3 point parameter calculated by the following (1) equation:

Ac_3=920-203vC+44.7Si+31.5Mo-30Mn-11Cr+40Al-15.2Ni+13.1+104V+40Ti (1)

is in a range of 850-960°C, an ideal critical diameter (D_I) calculated by the following (2) equation:

D_I=7.95vC(1+0.70Si)(1+3.3Mn)(1+2.16Cr)(1+3.0Mo)(1+0.36Ni)(1+5.0V) (2)

is in a range of 30-250mm, wherein the steel stock is carburized at a temperature in a range of 850-1000°C, quenched at a temperature in a range of 800-950°C, and tempered, and a structure of a non-carburized part of the thus obtained steel stock has a dual-phase structure consisting of martensite containing 10-70 area% of ferrite. In the present invention, when an Ac_3 point parameter and an ideal critical diameter (D_I) are calculated by the aforementioned (1) equation and (2) equation, there is a term relating to a prescribed component element in a right side of the (1) equation and the (2) equation, but regarding a chemical component composition, calculation is performed under the proviso that contents of Al, W, V and Ti which are component elements having no limitation are 0 (zero). Hereinafter, this is true also in the inventions described in claims 2 to 5. In addition, this is also true in comparative steels and the prior art steels in Examples described later.

[0018] The low strain type carburized and quenched steel stock for a gear of the invention described in claim 2 is the steel stock for a gear described in claim 1 which

further additionally contains at least one element selected from the group consisting of the following chemical component composition:

tungsten (W): 0.01-0.70wt.%, and

vanadium (V): 0.01-1.0wt.%.

[0019] The low strain type carburized and quenched steel stock for a gear of the invention described in claim 3 is the steel stock for a gear of the invention described in claim 1 which further additionally contains at least one element selected from the group consisting of the following chemical component composition:

aluminum (Al): 0.005-2.0wt.%,

titanium (Ti): 0.005-1.0wt.%,

niobium (Nb): 0.005-0.50wt.%, and

zirconium (Zr): 0.005-0.50wt.%.

[0020] The low strain type carburized and quenched steel stock for a gear of the invention described in claim 4 is the steel stock for a gear of the invention described in claim 1 which further additionally contains at least one element selected from the group consisting of the following chemical component composition:

tungsten (W): 0.01-0.70wt.%, and

vanadium (V):0.01-1.0wt.%, as well as

at least one element selected from the group consisting of the following chemical component composition:

aluminum (Al): 0.005-2.0wt.%,

titanium (Ti): 0.005-1.0wt.%,

niobium (Nb): 0.005-0.50wt.%, and

zirconium (Zr): 0.005-0.50wt.%.

[0021] The low strain type carburized and quenched steel stock for a gear of the invention described in claim 5 is the low strain type carburized and quenched steel stock for a gear of the invention described in any one of claims 1 to 4, in which the ideal critical diameter (D_I) is in the range of 30 to 150mm.

[0022]

[Mode for carrying out the invention] According to the present invention, by increasing contents of Si, Mo and V which are elements for raising an Ac_3 transformation temperature and improving quenching property, and Al, Ti and W for raising an Ac_3

transformation temperature, a ferrite·martensite dual-phase structure can be easily obtained by carburization and quenching treatment and, by absorption of an expansion strain of martensite by ferrite, a quenching strain amount is considerably decreased, and a hardness of a core part of a gear (hereinafter, referred to as "gear core part"; see Fig.4) at quenching can be sufficiently maintained, therefore, a fatigue strength comparable to that of the prior art steel is obtained.

[0023] In addition, in a gear of an automobile, for the purpose of improving a fatigue strength of a dedendum, shot peening treatment is performed in many cases. However, according to the steel stock of the present invention, since formation of a grain boundary oxidized layer at a surface is suppressed, and a quenching-unacceptable structure is not generated, when shot peening is performed, a fatigue strength of a dedendum is increased without deterioration of surface roughness. Further, by Si, Mo, W and V, a quenching softening resistance is increased, and a surface fatigue strength is increased.

[0024] Like this, in the present invention, respective elements in a steel stock exert various actions and effects, and chemical component elements to be contained in a steel stock consist of essential components and selective components. And, selective components are classified into two groups. Since improvement in quenching property is common among actions and effects of W and V as a selective component, these are classified into a first group and, since quenching strain suppression due to crystal particle miniaturization is common, Al, Ti, Nb and Zr are classified into a second group.

[0025] Then, the reason why the chemical component composition of the carburized and quenched steel stock for a gear of the present invention is limited to the aforementioned range will be described below.

(1) Carbon (C)

Carbon is a fundamental element necessary for guaranteeing a strength of a gear core part due to carburization and quenching and, in order to make the action being exerted, it is necessary that C is contained at 0.10wt.% or more. When C is less than 0.10wt.%, since a long time is necessary to obtain an effective carburization hardened layer depth, this is industrially unsuitable. On the other hand, when a carbon content exceeds 0.35wt.%, this leads to deterioration in toughness and reduction in cutting property.

Therefore, a carbon content should be limited to a range of 0.10-0.35%.

[0026] (2) Silicon (Si)

Silicon is an element which plays an important role as described below. That is, silicon is effective for preventing grain boundary oxidation of a surface layer, is a ferrite forming element, is effective for raising an Ac_3 transformation point, and is a relatively inexpensive element. Further, silicon increases a tempering softening resistance, and improves a surface fatigue strength. However, when a silicon content is less than 0.50wt.%, since a silicon concentration at a surface layer which binds to minor oxygen inevitably present in a carburization gas at carburization treatment is too low, the minor oxygen penetrates into a deep part of a steel stock, and a grain boundary oxidized layer becomes remarkably deep and, as a result, a fatigue strength is reduced. On the other hand, when a silicon content exceeds 2.5wt.% and becomes excessive, a ferrite amount becomes too much, not only a strength and toughness are reduced, but also a SiO_2 non-metal intervening substance is increased and, as a result, a fatigue strength is conversely reduced. Therefore, a silicon content should be limited to a range of 0.50 to 2.5wt.%.

[0027] (3) Manganese (Mn)

Manganese is an element which improves quenching property, and is effective for maintaining a strength of a gear core part and, in order to make the action exert, it is necessary that manganese is contained at 0.20wt.% or more. However, since manganese has the action of lowering an Ac_3 transformation point greatly, when a content thereof becomes great exceeding 2.50wt.%, not only a dual-phase structure of martensite and ferrite is not obtained, but also a hardness becomes too high, and cutting property is deteriorated. Therefore, a manganese content should be limited to a range of 0.20-2.50wt.%.

[0028] (4) Chromium (Cr)

Chromium is an element effective for improving quenching property like manganese and, in order to make the action exert, it is necessary that chromium is contained at 0.01wt.% or more. However, since chromium has the action of lowering an Ac_3 transformation point like manganese, when a content thereof becomesgreat exceeding 2.50wt.%, not only a dual-phase structure of martensite and ferrite is not obtained, but also a hardness becomes too high, and cutting property is deteriorated. Therefore, a

chromium content should be limited to a range of 0.01 to 2.50wt.%.

[0029] (5) Molybdenum (Mo)

Molybdenum is an element which raises an Ac_3 transformation point, is effective in generation of ferrite, and is effective for improving quenching property, a tempering softening resistance, toughness and a fatigue strength and, in order to make the action exert, it is necessary that molybdenum is contained at 0.01wt.% or more. However, molybdenum is an extremely expensive element and, even when molybdenum is added so that a content exceeds 0.70wt.%, the above effect is saturated, and economical disadvantage is resulted. Therefore, a molybdenum content should be limited to a range of 0.01-0.70wt.%.

[0030] (6) Nickel (Ni)

Nickel is an element effective for enhancing quenching property and toughness and, in order to make the action exert, it is necessary that nickel is contained at 0.01 wt.% or more. However, when a nickel content is great exceeding 2.0 wt.%, a hardness becomes too high, cutting property is deteriorated and, moreover, since nickel is an expensive element, it is economically disadvantageous. Therefore, a nickel content should be limited to a range of 0.01-2.0 wt.%.

[0031] (7) Tungsten (W)

Tungsten is an element effective for raising an Ac_3 transformation point to produce ferrite like molybdenum, increasing tempering softening resistance, improving a surface fatigue strength, and improving toughness and a dedendum fatigue strength and, in order to make the action exert, it is necessary that tungsten is contained at 0.01 wt.% or more. However, tungsten is also an expensive element and, when a content thereof is added exceeding 0.70 wt.%, this leads to economical disadvantage for its effect. Therefore, a tungsten content should be limited to a range of 0.01-0.70 wt.%. When tungsten and molybdenum are added together, a total amount is desirably 0.70 wt.% or less. When a total amount exceeds 0.70 wt.%, a carburization and quenching strain becomes great, being not preferable.

[0032] (8) Vanadium (V)

Vanadium has the great action of raising an Ac_3 transformation point, is an element effective for enhancing quenching property, improving a dedendum fatigue strength, increasing tempering softening resistance, and improving a surface fatigue strength, and

has the action of producing carbide nitride, miniaturizing a crystal particle and suppressing a quenched strain small and, in order to make the action exert, it is necessary that vanadium is contained at 0.01 wt.% or more. However, when a vanadium content exceeds 1.0 wt.%, the effect is saturated, this is economically disadvantageous, and an amount of carbide nitride is increased, leading to reduction in toughness. Therefore, a vanadium content should be limited to a range of 0.01-1.0 wt.%.

[0033] (9) Aluminum (An)

Aluminum binds to nitrogen to produce AlN, decreases a strain at quenching by miniaturizing a crystal particle, and is an element effective for improving toughness and a fatigue strength. For this, it is necessary that aluminum is contained at 0.005 wt.% or more. In addition, aluminum is a ferrite forming element like silicon, and can greatly raise an Ac_3 transformation point economically. However, when an aluminum content is increased exceeding 2.0 wt.%, an alumina-based intervening substance is increased, leading to reduction in toughness and a fatigue strength. Therefore, an aluminum content should be limited to a range of 0.005-2.0 wt.%. In addition, when silicon and aluminum are used together, in order to maintain cleanability and toughness of a steel, it is desirable that a total amount is regulated to 2.6 wt.% or less.

[0034] (10) Titanium (Ti)

Titanium is also a ferrite forming element, has the great action of raising an Ac_3 transformation point, is an element effective for miniaturizing austenite crystal particle, and has the action of enhancing a yield strength of a carburized part and an interior of a tooth to contribute to improvement in a fatigue strength and, in order to make the effect exert, it is necessary that titanium is contained at 0.005 wt.% or more. However, when a titanium content exceeds 1.0 wt.%, not only the effect is saturated, leading to economical disadvantage, but also an amount of carbide nitride becomes too much, leading to reduction in toughness. Therefore, a titanium content should be limited to a range of 0.005-1.0 wt.%.

[0035] (11) Niobium (Nb)

Niobium is also an element effective for miniaturizing an austenite crystal particle and, in order to make the action exert, it is necessary that niobium is contained at 0.005 wt.%. However, when a niobium content exceeds 0.50 wt.%, not only the effect is saturated,

leading to economical disadvantage, but also an amount of carbide nitride becomes great, leading to reduction in toughness. Therefore, a niobium content should be limited to a range of 0.005-0.50 wt.%.

[0036] (12) Zirconium (Zr)

Zirconium is also an element effective for miniaturizing an austenite crystal particle like titanium and niobium and, in order to make the action exert, it is necessary that zirconium is contained at 0.005 wt.% or more. However, when a zirconium content exceeds 0.50 wt.%, not only the effect is saturated, leading to economical disadvantage, but also an amount of carbide nitride becomes great, leading to reduction in toughness. Therefore, a zirconium content should be limited to a range of 0.005-0.50 wt.%.

[0037] In the steel of the present invention, a content of P, Cu and O as unavoidable impurities is desirably as low as possible. In addition, for the purpose of miniaturizing a crystal particle, if necessary, it is acceptable that N is added up to 0.20 wt.%. In addition, for improving cutting property, if necessary, a free-machining element such as S, Pb, Ca and Se may be contained.

[0037] (13) Ac_3 point parameter: An example of heat treatment pattern in carburization treatment by the conventional method is shown in Fig. 5. A steel stock for a gear is carburized at 920°C to diffuse carbon into an interior of a steel, thereafter, in order to reduce a strain, a temperature is retained at 850°C which is a lower temperature than a carburization temperature, and rapid cooling is performed with an oil or the like to carry out quenching. Therefore, if an Ac_3 point parameter calculated by the following (1) equation of a steel stock for a gear is lower than 850°C, even when the temperature is retained at 850°C after carburization, ferrite cannot be maintained in austenite. On the other hand, when the Ac_3 point parameter exceeds 960°C, an amount of ferrite in austenite becomes excessive, and a strength of a gear core part is deficient. Therefore, an Ac_3 point parameter calculated by the following (1) equation:

$$Ac_3=920-203\sqrt{C}+44.7Si+31.5Mo-30Mn-11Cr+40Al-15.2Ni+13.1W+104V+40Ti \quad (1)$$

of the present invention steel should be limited to a range of 850-960°C.

[0039] (14) Ideal critical diameter (D_I): An ideal critical diameter (D_I) is a value representing quenching property of a steel. Generally, an austenite particle size number of a steel stock product required when a steel stock is used as a steel stock

product is No. 8, and this is the same in a carburized and quenched gear. In order to maintain a desired fatigue strength, it is necessary that an ideal critical diameter (D_I) value calculated by the following (2) equation:

D_I=7.95√C(1+0.70Si)(1+3.3Mn)(1+2.16Cr)(1+3.0Mo)(1+0.36Ni)(1+5.0V) (2)

which is an equation for calculating an ideal critical diameter (D_I) of a steel stock when an austenite particle size number is No. 8 is 30 mm or more. On the other hand, when the ideal critical diameter (D_I) value exceeds 250 mm, the effect of absorbing a transformation strain of martensite due to ferrite present in an austenite structure in admixture thereof is abolished, and a quenching strain is increased. Therefore, a chemical component composition of a gear should be limited so that an ideal critical diameter (D_I) value calculated by the aforementioned (2) equation letting an austenite particle size number to be No. 8 is in a range of 30-250 mm. And, in order to further reduce a quenching strain, it is desirable that the value is limited to a range of 30-150 mm. In addition, when an austenite particle size number is other than No. 8, since a coefficient of a right side of the (2) equation is determined depending on the particle size number thereof, a chemical component composition of a gear should be limited so that a calculated value using an equation for calculating D_I depending on an austenite particle size number is in the aforementioned range.

[0040] Regarding carburization and quenching temperature

Then, a carburization temperature for a steel stock should be such a temperature at which carburization treatment can be performed easily and effectively. When a carburization temperature is lower than 850°C, a carbon diffusing rate is slow, and a long time is necessary for obtaining a desired carburization depth. On the other hand, when a carburization temperature exceeds 1000°C, a crystal particle is easily enlarged, and oxidization of a steel stock surface becomes remarkable and, as a result, surface fatigue property is reduced. Therefore, a carburization temperature should be limited to a range of 850 to 1000°C.

[0041] When a temperature of quenching which is performed after carburization treatment is lower than 800°C, a long time is necessary for lowering a temperature of the carburization furnace to that temperature. On the other hand, when a quenching temperature exceeds 950°C, it becomes difficult to maintain area% of ferrite in a

martensite structure obtained after quenching at a desired value, and a quenching strain amount is also increased. Therefore, a quenching temperature should be limited to a range of 800-950°C.

[0042] Regarding a ferrite amount in a structure of interior of a tooth (structure of non-carburized part)

When a ferrite amount of a structure in an interior of a tooth which is a non-carburized part after carburization and quenching·tempering is less than 10%, a transformation strain of martensite cannot be sufficiently absorbed, and a quenching strain amount cannot be suppressed small. On the other hand, when the ferrite amount exceeds 70%, it becomes difficult to maintain a desired strength and toughness in an interior of a tooth. Therefore, a ferrite amount of a structure in an interior of a tooth should be limited to a range of 10-70%. Thereupon, martensite may partially contain retained austenite and/or bainite.

[0043]

[Example] Then, the present invention will be explained in more detail by comparing Examples and Comparative Examples. Ingots for test steels of the present invention steels No. 1-31 which are in a range of the present invention conditions shown in Tables 1-3 (chemical component composition, Ac_3 point parameter, ideal critical diameter (D_I), carburization temperature, quenching temperature, and ferrite area% of non-carburized part after carburization and quenching·tempering), as well as comparative steels No. 1-21 which are outside the range of the present invention conditions shown in Tables 4 and 5, and the prior art steels No. 1-4 shown in Table 6 were prepared.

[0044]

[Table 1]

No.		Chemical component (wt%)												Ac$_3$ point parameter (°C)	D_I value (mm)	Carburization temperature (°C)	Quenching temperature (°C)	Ferrite area rate of interior of tooth (%)
		C	Si	Mn	Cr	Mo	Ni	Al	W	V	Ti	Nb	Zr					
Present invention steel	1	0.21	1.40	0.62	0.50	0.02	0.05	-	-	-	-	-	-	866	48	920	850	15
	2	0.12	0.63	0.43	0.26	0.52	1.75	-	-	-	-	-	-	851	63	860	810	13
	3	0.13	2.38	0.35	0.70	0.55	0.07	-	-	-	-	-	-	951	112	920	850	65
	4	0.28	1.31	1.05	0.15	0.69	0.01	-	-	-	-	-	-	859	147	920	850	22
	5	0.14	2.45	0.38	2.45	0.20	0.88	-	-	-	-	-	-	908	241	920	850	45
	6	0.15	2.48	2.45	0.05	0.03	0.35	-	-	-	-	-	-	873	104	920	850	28
	7	0.20	1.60	0.65	0.48	0.20	1.95	-	-	-	-	-	-	852	131	920	850	12
	8	0.11	0.75	1.85	0.20	0.10	0.66	1.20	-	0.36	0.01	-	-	907	184	920	850	44
	9	0.15	0.51	0.85	0.16	0.68	0.06	1.93	-	-	0.35	-	0.03	948	66	980	940	56
	10	0.13	1.97	0.27	1.45	0.03	1.04	0.035	-	-	-	-	-	897	80	920	850	36

[0045]

[Table 2]

No.		Chemical component (wt%)												Ac_3 point parameter (°C)	D_I value (mm)	Carburization temperature (°C)	Quenching temperature (°C)	Ferrite area rate of interior of tooth (%)
		C	Si	Mn	Cr	Mo	Ni	Al	W	V	Ti	Nb	Zr					
Present invention steel	11	0.15	2.45	0.22	2.40	0.03	0.05	-	0.65	0.28	-	-	-	955	238	920	850	68
	12	0.25	0.95	0.25	1.08	0.02	0.04	-	-	0.95	-	-	0.45	940	249	920	900	58
	13	0.33	0.55	0.45	0.02	0.35	0.06	1.20	-	-	0.78	0.46	-	903	34	920	850	40
	14	0.25	0.65	1.05	1.20	0.48	0.01	-	0.35	-	0.95	0.05	-	860	227	920	850	16
	15	0.34	1.05	0.31	0.52	0.60	0.15	0.012	0.02	0.02	-	-	-	853	112	920	850	31
	16	0.22	1.45	0.68	0.45	0.58	1.95	0.87	-	-	-	-	-	887	224	910	840	38
	17	0.11	1.90	1.86	0.26	0.35	0.86	-	-	-	-	-	-	876	184	910	840	35
	18	0.16	0.52	0.86	0.17	0.69	0.06	1.96	-	-	-	-	0.29	933	71	910	840	53
	19	0.22	1.45	0.76	0.75	0.21	0.35	0.021	-	-	-	-	-	861	127	910	840	18
	20	0.13	1.76	0.53	1.15	0.12	1.88	-	-	-	-	-	-	872	140	910	840	30

[0046]

[Table 3]

No.		Chemical component (wt%)												Ac_3 point parameter (°C)	D_I value (mm)	Carburization temperature (°C)	Quenching temperature (°C)	Ferrite area rate of interior of tooth (%)
		C	Si	Mn	Cr	Mo	Ni	Al	W	V	Ti	Nb	Zr					
Present invention steel	21	0.19	1.36	0.80	0.14	0.25	0.02	-	0.25	0.35	0.35	0.42	0.43	928	155	910	840	53
	22	0.20	1.45	0.68	0.05	0.51	0.25	-	-	-	-	-	-	885	71	910	840	32
	23	0.25	2.16	0.31	2.38	0.15	0.55	-	-	-	-	-	-	875	215	910	840	25
	24	0.28	2.35	0.56	0.23	0.12	1.55	0.068	0.31	0.25	0.41	-	0.23	927	226	910	840	48
	25	0.18	1.85	0.84	0.56	0.65	0.12	0.012	-	-	-	0.03	-	904	199	910	840	44
	26	0.13	0.67	1.16	0.35	0.44	1.15	1.85	0.38	0.04	0.03	-	0.04	918	141	910	840	46
	27	0.13	0.53	0.56	1.15	0.35	0.75	0.96	0.05	-	0.91	0.25	-	916	102	910	840	48
	28	0.21	1.45	0.95	0.55	0.03	0.65	-	-	0.35	-	-	0.18	884	246	910	840	36
	29	0.17	2.41	0.95	0.02	0.42	1.86	-	-	-	-	-	-	900	143	910	840	45
	30	0.16	0.56	0.63	0.78	0.02	0.02	1.85	-	-	-	-	-	910	39	910	840	43
	31	0.15	1.75	0.78	1.15	0.22	0.35	0.026	-	-	-	-	-	886	157	910	840	35

[0047]

[Table 4]

No.		Chemical component (wt%)												Ac_3 point parameter (°C)	D_I value (mm)	Carburization temperature (°C)	Quenching temperature (°C)	Ferrite area rate of interior of tooth (%)
		C	Si	Mn	Cr	Mo	Ni	Al	W	V	Ti	Nb	Zr					
Comparative steel	1	0.20	1.44	0.70	0.50	0.77	0.05	-	-	-	-	-	-	890	166	920	850	35
	2	0.12	2.75	0.55	0.35	0.51	0.16	-	-	-	-	-	-	965	107	920	850	76
	3	0.25	0.73	0.85	1.25	0.20	0.03	-	-	0.52	1.15	-	-	917	492	920	850	45
	4	0.08	0.45	0.16	0.52	0.25	1.12	0.02	-	-	-	-	0.52	864	24	920	850	34
	5	0.19	1.70	1.60	0.76	0.35	0.04	-	0.75	-	-	0.55	-	871	263	920	850	27
	6	0.37	1.56	0.36	2.56	0.03	0.25	0.13	0.25	-	-	-	-	832	172	900	840	5
	7	0.27	0.55	0.25	0.35	0.25	2.15	2.10	-	1.05	0.03	-	-	997	356	980	920	81
	8	0.14	1.78	2.65	0.16	0.02	0.03	0.019	-	-	-	0.03	-	843	94	920	850	7
	9	0.24	0.69	0.72	1.15	0.21	0.03	0.86	-	0.52	1.15	-	-	957	403	910	840	65
	10	0.08	0.45	0.16	0.52	0.25	1.15	-	-	-	-	0.54	-	862	24	910	840	35

[0048]

[Table 5]

No.		Chemical component (wt%)												Ac_3 point parameter (°C)	D_I value (mm)	Carburization temperature (°C)	Quenching temperature (°C)	Ferrite area rate of interior of tooth (%)
		C	Si	Mn	Cr	Mo	Ni	Al	W	V	Ti	Nb	Zr					
Comparative steel	11	0.36	1.60	0.26	2.58	0.03	0.20	0.13	0.35	-	-	-	-	841	144	910	840	5
	12	0.33	0.56	0.25	0.35	0.25	2.15	2.20	-	1.03	0.15	-	-	993	458	910	840	81
	13	0.37	1.75	0.61	2.58	0.08	0.12	0.035	-	-	-	-	-	830	276	910	840	5
	14	0.19	0.78	0.85	0.45	0.25	2.11	-	-	-	1.09	-	-	855	125	910	840	13
	15	0.37	1.75	0.56	2.61	0.10	0.14	0.034	-	-	-	-	-	831	278	910	840	5
	16	0.18	0.82	0.83	0.43	0.25	1.86	-	-	-	1.12	-	-	865	112	910	840	14
	17	0.20	0.61	1.05	0.97	0.76	0.35	2.18	-	-	-	0.61	0.18	920	259	910	840	48
	18	0.25	0.55	0.53	0.25	0.05	0.25	0.11	-	1.08	-	-	0.55	938	187	910	840	57
	19	0.37	1.87	0.76	0.49	0.22	0.28	0.025	-	-	-	-	-	854	147	910	840	12
	20	0.18	0.78	1.56	0.56	0.75	0.02	2.15	-	-	-	-	-	925	232	910	840	50
	21	0.18	2.41	1.35	1.60	0.03	0.01	-	0.76	-	-	0.58	-	894	241	910	840	38

[0049]

[Table 6]

No.		Chemical component (wt%)												Ac_3 point parameter (°C)	D_I value (mm)	Carburization temperature (°C)	Quenching temperature (°C)	Ferrite area rate of interior of tooth (%)
		C	Si	Mn	Cr	Mo	Ni	Al	W	V	Ti	Nb	Zr					
Prior art steel	1	0.21	0.24	1.44	0.52	0.03	0.01	-	-	-	-	-	-	789	57	920	850	5
	2	0.22	0.25	0.76	1.11	0.18	0.05	0.026	-	-	-	0.03	-	807	82	920	850	6
	3	0.21	0.26	0.56	0.51	0.17	1.68	0.025	-	-	-	-	-	797	62	920	850	7
	4	0.34	0.23	0.81	1.08	0.18	0.04	0.031	-	-	-	-	-	782	103	920	850	4

[0050] A comparative steel No. 1 is a steel in which a Mo content is large exceeding a range of the present invention, a comparative steel No. 2 is a steel in which a Si content is large exceeding a range of the present invention, and an Ac_3 point parameter is as high as 965°C, a comparative steel No. 3 is a steel in which a Ti content is large exceeding a range of the present invention, and an ideal critical diameter (D_I) is also large exceeding a range of the present invention, a comparative steel No. 4 is a steel in which contents of C, Si and Mn are low outside a range of the present invention, and an ideal critical diameter (D_I) is also small outside a range of the present invention, a comparative steel No. 5 is a steel in which W is more exceeding a range of the present invention, and an ideal critical diameter (D_I) is also large exceeding a range of the present invention, a comparative steel No. 6 is a steel in which contents of C and Cr are more exceeding a range of the present invention and, for this reason, an Ac_3 point parameter is low outside a range of the present invention, a comparative steel No. 7 is a steel in which contents of Al, Ni and V are more exceeding a range of the present invention, and an Ac_3 point parameter is as high as 997°C exceeding a range of the present invention, and a comparative steel No. 8 is a steel in which a Mn content is more exceeding a range of the present invention, and an Ac_3 point parameter is as low as 843°C outside a range of the present invention. A comparative steel No. 9 is a steel in which Ti is more exceeding a range of the present invention, and an ideal critical diameter (D_I) is high exceeding a range of the present invention, a comparative steel No. 10 is a steel in which C, Si and Mn are low outside a range of the present invention, an ideal critical diameter (D_I) is low outside a range of the present invention, and Nb is high, a comparative steel No. 11 is a steel in which C, and Cr are more exceeding a range of the present invention, and an Ac_3 point parameter is lower than a range of the present invention, and a comparative steel No. 12 is a steel in which Al, Ni and V are more exceeding a range of the present invention, an Ac_3 point parameter is high as 968°C, and an ideal critical diameter (D_I) is also high exceeding a range of the present invention. A comparative steel No. 13 is a steel in which C and Cr are more exceeding a range of the present invention, an Ac_3 point parameter is lower than a range of the present invention, and an ideal critical diameter (D_I) is also higher than a range of the present invention, and a comparative steel No. 14 is a steel in which Ni and Ti are more

exceeding a range of the present invention. A comparative steel No. 15 is a steel in which C and Cr are more exceeding a range of the present invention, an Ac_3 point parameter is lower than a range of the present invention, and an ideal critical diameter (DI) is high exceeding a range of the present invention, and a comparative steel No. 16 is a steel in which Ti is more exceeding a range of the present invention. A comparative steel No. 17 is a steel in which Mo, Al and Nb are more exceeding a range of the present invention, and an ideal critical diameter (D_I) is greater than the present invention, and a comparative steel No. 18 is a steel in which V and Zr are more exceeding a range of the present invention. A comparative steel No. 19 is a steel in which C is high exceeding a range of the present invention, a comparative steel No. 20 is a steel in which Al is more exceeding a range of the present invention, and a comparative No. 21 is a steel in which W and Nb are more exceeding a range of the present invention.

[0051] The prior art steels No. 1-4 are steels prescribed by the conventional JIS, the prior art steel No. 1 is JIS SMnC420, the prior art steel No. 2 is JIS SCM420, the prior art steel No. 3 is JIS SNCM420, and the prior art steel No. 4 is JIS SCM435, and all are steels in which a Si content and an Ac_3 point parameter are small outside a range of the present invention.

[0052] Ingots of the present invention steels, comparative steels and the prior art steels were hot rolled to prepare round bar steels having a diameter of 20-90 mm, and the resulting round bar steels were subjected to normalizing treatment. From round bar steels after normalizing treatment, quenching strain test pieces and fatigue test pieces were collected. Respective test pieces were subjected to carburization and quenching · tempering treatment, and a carburization and quenching strain amount, rotation bending fatigue property and gear fatigue property were tested. Further, 20 mm round bar steels after normalizing were subjected to carburization and quenching · tempering, tensile test pieces and impact test pieces were collected, and a strength and toughness were tested. Respective test methods are as follows. A retaining temperature at a quenching temperature is 0.5 hour for oil quenching, in all cases, and tempering was performed under 160°C×2 hours in all cases.

[0053] (1) Carburization and quenching strain amount: From round bar steels having a

diameter of 65 mm, Navy C test pieces were prepared. Fig. 1 shows a front view of a Navy C test piece, and Fig. 2 shows its side view. A Navy C test piece 1 has an opening part 2 and a circular space 3 in a disk body as shown in both figures, and a dimension of each part of a test piece is as follows:

Test piece diameter (a): 60 mm, thickness (b): 12 mm, diameter of circular space (c): 34.8 mm, opening part interval (d): 6 mm, distance between test piece center and opening part circle center (p): 10.2 mm.

[0054] Measurement of a strain amount after carburization and quenching·tempering was performed by measuring a change rate before and after carburization and quenching, of an opening part interval of a Navy C test piece. Using a steel stock for a gear showing such a great strain that a strain amount after carburization and quenching·tempering of a Navy C test piece exceeds 1.0%, a gear was processed and, when this is subjected to carburization and quenching·tempering, great deformation is generated, a tooth form must be correction-treated by machine cutting, and machine cutting cannot be omitted. In order to allow a steel stock only after carburization and quenching·tempering without tooth form correction cutting to be used as a gear, it is necessary that a strain amount after carburization and quenching·tempering in a Navy C test piece is 1.0% or smaller and, in order that a steel stock can be used without performing tooth form correction cutting regardless of a shape and a dimension of a gear, 0.5% or smaller is further desirable.

[0055] Ten pieces of Navy C test pieces 1 having the aforementioned shape were prepared per each test steel, these test pieces 1 were subjected to carburization and quenching, and then tempering, a change rate before and after carburization and quenching·tempering, of an opening part interval (d) of these test pieces was measured, and this value was defined as carburization and quenching strain amount. Tables 7 to 12 show test results of a carburization and quenching strain amount, that is, a mean of n=10, and a dispersion.

[0056]

[Table 7]

No.		Quenching strain amount (%)		Depth of grain boundary oxidized layer (μm)	Depth of quenching-unacceptable layer (μm)	Depth of effective hardened layer (mm)	Rotation bending fatigue strength (N/mm²)	Gear fatigue durability torque (Nm)	Presence or absence of chipping	Strength of gear core part (N/mm²)	Impact value of gear core part (J/cm²)
		Mean	Dispersion								
Present invention steel	1	0	0	2	0	0.58	740	325	None	980	68
	2	0.02	0	2	0	0.62	750	345	None	1026	72
	3	0.25	0.03	1	0	0.65	765	355	None	1085	85
	4	0.46	0.05	2	0	0.60	775	365	None	1033	83
	5	0.81	0.08	2	0	0.76	785	375	None	1167	105
	6	0.18	0.03	1	0	0.63	760	350	None	1070	75
	7	0.27	0.04	2	0	0.72	770	360	None	1125	125
	8	0.51	0.05	1	0	0.80	780	370	None	1250	85
	9	0.02	0.01	1	0	0.61	750	340	None	990	70
	10	0.03	0.01	2	0	0.56	740	330	None	985	71

[0057]

[Table 8]

No.		Quenching strain amount (%)		Depth of grain boundary oxidized layer (μm)	Depth of quenching-unacceptable layer (μm)	Depth of effective hardened layer (mm)	Rotation bending fatigue strength (N/mm^2)	Gear fatigue durability torque (Nm)	Presence or absence of chipping	Strength of gear core part (N/mm^2)	Impact value of gear core part (J/cm^2)
		Mean	Dispersion								
Present invention steel	11	0.86	0.09	1	0	0.88	785	370	None	1275	85
	12	0.95	0.12	2	0	0.95	795	380	None	1350	68
	13	0	0	1	0	0.51	730	315	None	920	75
	14	0.75	0.08	2	0	0.90	780	375	None	1265	76
	15	0.21	0.03	1	0	0.63	760	350	None	1080	70
	16	0.75	0.07	1	0	0.70	775	365	None	1120	127
	17	0.51	0.06	2	0	0.81	780	375	None	1240	88
	18	0.02	0	1	0	0.62	760	340	None	960	67
	19	0.27	0.04	1	0	0.72	770	360	None	1125	125
	20	0.42	0.04	2	0	0.60	780	360	None	1030	105

[0058]

[Table 9]

No.		Quenching strain amount (%)		Depth of grain boundary oxidized layer (μm)	Depth of quenching-unacceptable layer (μm)	Depth of effective hardened layer (mm)	Rotation bending fatigue strength (N/mm^2)	Gear fatigue durability torque (Nm)	Presence or absence of chipping	Strength of gear core part (N/mm^2)	Impact value of gear core part (J/cm^2)
		Mean	Dispersion								
Present invention steel	21	0.46	0.04	1	0	0.65	770	360	None	1050	85
	22	0.03	0.01	1	0	0.58	745	335	None	990	92
	23	0.66	0.06	2	0	0.85	770	370	None	1250	76
	24	0.71	0.07	1	0	0.90	780	375	None	1280	87
	25	0.65	0.06	1	0	0.80	780	370	None	1250	95
	26	0.42	0.04	2	0	0.63	765	355	None	1030	84
	27	0.15	0.01	1	0	0.60	750	350	None	1060	90
	28	0.91	0.08	1	0	0.78	785	380	None	1210	76
	29	0.45	0.05	2	0	0.72	775	360	None	1200	90
	30	0.05	0.01	1	0	0.60	750	350	None	1010	110
	31	0.41	0.05	2	0	0.65	775	360	None	1030	90

[0059]

[Table 10]

No.		Quenching strain amount (%)		Depth of grain boundary oxidized layer (μm)	Depth of quenching-unacceptable layer (μm)	Depth of effective hardened layer (mm)	Rotation bending fatigue strength (N/mm^2)	Gear fatigue durability torque (Nm)	Presence or absence of chipping	Strength of gear core part (N/mm^2)	Impact value of gear core part (J/cm^2)
		Mean	Dispersion								
Comparative steel	1	1.25	0.25	1	0	0.75	775	365	None	1149	81
	2	0.25	0.08	4	1	0.62	660	265	Presence	860	35
	3	2.85	0.86	5	3	1.06	680	255	Presence	1240	37
	4	0.04	0.02	10	7	0.41	670	245	Presence	820	65
	5	1.07	0.21	2	1	0.85	700	285	Presence	1280	45
	6	2.65	0.76	5	3	0.75	720	280	Presence	1200	55
	7	2.56	0.81	4	2	1.25	710	290	Presence	1070	45
	8	2.45	0.86	17	16	0.60	735	300	None	1005	35
	9	2.90	0.88	6	4	1.07	685	250	Presence	1230	38
	10	0.05	0.02	11	8	0.40	665	245	Presence	800	66

[0060]

[Table 11]

No.		Quenching strain amount (%)		Depth of grain boundary oxidized layer (μm)	Depth of quenching-unacceptable layer (μm)	Depth of effective hardened layer (mm)	Rotation bending fatigue strength (N/mm^2)	Gear fatigue durability torque (Nm)	Presence or absence of chipping	Strength of gear core part (N/mm^2)	Impact value of gear core part (J/cm^2)
		Mean	Dispersion								
Comparative steel	11	2.70	0.78	6	4	0.71	695	260	Presence	1055	43
	12	2.55	0.76	3	2	1.16	715	285	Presence	1310	66
	13	2.48	0.70	2	1	0.86	720	280	Presence	1180	35
	14	0.30	0.03	5	3	0.72	695	265	Presence	1060	41
	15	2.15	0.66	3	2	0.96	700	285	Presence	1650	42
	16	0.26	0.03	6	5	0.66	695	265	Presence	1080	44
	17	1.13	0.25	4	3	0.78	700	275	Presence	1230	36
	18	0.70	0.07	14	11	0.75	710	300	Presence	1080	35
	19	0.52	0.05	2	1	0.75	670	250	Presence	1150	45
	20	0.95	0.10	10	9	0.90	705	290	Presence	1200	54
	21	1.75	0.21	3	2	1.05	720	285	Presence	1230	65

[0061]

[Table 12]

No.		Quenching strain amount		Depth of grain boundary oxidized layer (μm)	Depth of quenching-unacceptable layer (μm)	Depth of effective hardened layer (mm)	Rotation bending fatigue strength (N/mm^2)	Gear fatigue durability torque (Nm)	Presence or absence of chipping	Strength of gear core part (N/mm^2)	Impact value of gear core part (J/cm^2)
		Mean	Dispersion								
Prior art steel	1	2.49	0.68	15	14	0.56	690	290	Presence	990	69
	2	2.85	0.70	18	16	0.60	685	285	Presence	1080	83
	3	2.56	0.75	13	12	0.58	725	290	Presence	980	88
	4	3.56	1.05	16	15	0.85	730	300	Presence	1150	45

[0062] (2) Ferrite area% of non-carburized part: Then, using test pieces for which a carburized and quenching strain amount had been already measured, ferrite area% of a ferrite-martensite dual-phase structure of a non-carburized part after carburization and quenching·tempering of each test steel was measured by a microscope investigation test, this is defined as ferrite area% of an interior of a tooth, and this ferrite area% is shown in Tables 1 to 6.

[0063] (3) Rotation bending fatigue property: From round bar steels having a diameter of 20 mm, test pieces having a parallel part diameter of 10 mm were collected, and rotation bending fatigue test pieces in which a notch (stress concentration coefficient a=1.8) having a depth of 1 mm was provided on a parallel part over an entire circular circumference in a direction vertical thereto were prepared, the test pieces were subjected to carburization and quenching·tempering treatment under the same conditions as those for Navy C test pieces, subjected to shot peening treatment (arc height: 0.6 mmA, coverage: 300%), and such the treated test pieces were subjected to a rotation bending fatigue test 10^7 times using an Ono-type rotation bending fatigue test machine, and its rotation bending fatigue strength was measured. Measurement results of a rotation bending fatigue strength are also described in Tables 7 to 9.

[0064] (4) Gear fatigue property, as well as grain boundary oxidized layer depth, quenching-unacceptable layer depth and effective hardened layer depth: From round bar steels having a diameter of 90 mm, test gears having an external diameter of 75 mm, a tooth width of 10 mm, a module of 2.5, and the tooth number of 28 were prepared by cutting procession, subjected to carburization and quenching·tempering and shot peening treatment under the same conditions as those for the aforementioned rotation bending fatigue property, the resulting test pieces were subjected to a gear fatigue test at a rotation number: 3000 rpm using a power circulation-type gear fatigue test machine, a torque value at which damage did not occur at a repetition number of 10^7 was obtained as a dedendum strength of a gear. Tables 7 to 9 also describe test results of a gear fatigue durability torque, and the presence or the absence of chipping. Further, a tooth part was excised from a gear which had been subjected to a gear fatigue test to prepare a prescribed test piece, a grain boundary oxidized layer depth, a quenching-unacceptable layer depth, and an effective hardened layer depth accompanied with carburization and

quenching were measured, and these are also described in Tables 7 to 9.

[0065] (5) Strength and impact value: From 25 mmf round bars after carburization and quenching·tempering, JIS No. 4 tensile test pieces (parallel part diameter: 14 mmf), and JIS No. 3 Charpy test pieces were prepared, a tensile test and an impact test were performed, thereby, a strength of a gear core part, and toughness of a gear core part were assessed. Tables 7 to 9 also describe test results of a strength and toughness.

[0066] From Tables 1 to 6, and Tables 7 to 12, the following matters are clear. In a comparative steel No. 1, a Mo content is great exceeding a range of the present invention and, for this reason, a quenching strain was great exceeding 1.0%. In a comparative steel No. 2, a Si content is great exceeding a range of the present invention and, for this reason, a sufficient strength cannot be maintained, and a rotation bending fatigue strength, and a gear fatigue durability torque are low. In a comparative steel No. 3, a Ti content is great exceeding a range of the present invention and, for this reason, an impact value of a gear core part is low. In addition, an ideal critical diameter (D_I) is also great outside a range of the present invention, and a quenching strain is great. In a comparative steel No. 4, contents of C, Si and Mn are small outside a range of the present invention, and an ideal critical diameter (D_I) is also small outside a range of the present invention and, for this reason, a sufficient strength cannot be maintained, and a rotation bending fatigue strength, and a gear fatigue durability torque are low. In addition, a Zr content is high outside a range of the present invention and, for this reason, an impact value of a gear core part is low.

[0067] In a comparative steel No. 5, a W content is great exceeding a range of the present invention, and an ideal critical diameter (D_I) is great outside a range of the present invention and, for this reason, a quenching strain is great exceeding 1.0%. In addition, a Nb content is high outside a range of the present invention and, for this reason, an impact value of a gear core part is low. In a comparative steel No. 6, contents of C and Cr are great exceeding a range of the present invention and, for this reason, an Ac_3 point parameter is low outside a range of the present invention, and a quenching strain is great. In a comparative steel No. 7, an Al content is great exceeding a range of the present invention and, for this reason, an impact value of a gear core part is low. In addition, contents of Ni and V are great exceeding a range of the

present invention, and an ideal critical diameter (D_I) is great outside a range of the present invention and, for this reason, a quenching strain is great. In a comparative steel No. 8, a Mn content is great exceeding a range of the present invention, and an Ac_3 point parameter is low outside a range of the present invention and, for this reason, a ferrite area rate is less than 10%, and a quenching strain is great. In a comparative steel No. 9, Ti content is great exceeding a range of the present invention and, for this reason, an impact value of a core part is low. In addition, an ideal critical diameter (D_I) is great outside a range of the present invention, and a quenching strain is great. In a comparative steel No. 10, C, Si, and Mn contents are small outside a range of the present invention and, for this reason, a sufficient strength cannot be maintained, and a rotation bending fatigue strength, and a gear fatigue durability torque are low. In addition, Nb content is high outside a range of the present invention and, for this reason, an impact value is low. In a comparative steel No. 11, C, and Cr contents are large exceeding a range of the present invention and, for this reason, an Ac_3 point parameter is low, sufficient ferrite cannot be maintained, and an ideal critical diameter (D_I) is great outside a range of the present invention, and a quenched strain is great. In a comparative steel No. 12, Al content is large exceeding a range of the present invention and, for this reason, an Ac_3 point parameter is high outside a range of the present invention and, for this reason, a sufficient fatigue strength cannot be maintained. In addition, Ni is more exceeding a range of the present invention, an ideal critical diameter (D_I) is too great, and a quenched strain is great. In a comparative steel No. 13, C, and Cr contenta are large exceeding a range of the present invention, an Ac_3 point parameter is lower than a range of the present invention, and an ideal critical diameter (D_I) is higher than a range of the present invention and, for this reason, a quenching strain is great exceeding 1%. In a comparative steel No. 14, Ni and Ti are more exceeding a range of the present invention, and toughness of a core part is inferior. A comparative steel No. 15 is a steel in which C and Cr contents are large exceeding a range of the present invention, an Ac_3 point parameter is lower than a range of the present invention, and an ideal critical diameter (D_I) is high exceeding a range of the present invention and, for this reason, toughness of a core part is low, and a quenching strain is great exceeding 1%. In a comparative steel No. 16, Ti content is large exceeding a range of the present invention and, for this reason, toughness of a core part

is low, and a rotation bending fatigue strength, and a gear fatigue durability torque are low. In a comparative steel No. 17, Mo, Al, and Nb are more exceeding a range of the present invention, and an ideal critical diameter (D_I) is greater than that of the present invention and, for this reason, toughness of a core part is low, and a rotation bending fatigue strength, and a gear fatigue durability torque are low. In a comparative steel No. 18, V and Zr are more exceeding a range of the present invention and, for this reason, toughness of a core part is low, and a rotation bending fatigue strength, and a gear fatigue durability torque are low. In a comparative steel No. 19, a C content is more outside a range of the present invention and, for this reason, toughness is low. In a comparative steel No. 20, an Al content is more exceeding a range of the present invention and, for this reason, toughness is low. In a comparative steel No. 21, contents of W and Nb are more exceeding a range of the present invention and, for this reason, toughness and a fatigue strength are low.

[0068] In addition, in the prior art steels No. 1-4, a ferrite area rate is 4-7%, and small outside a range of the present invention, a grain boundary oxidized layer depth and a quenching-unacceptable layer depth are great, and a quenching strain amount is great.

[0069] To the contrary, in the present invention steels No. 1-30, a grain boundary oxidized layer is considerably reduced as compared with the prior art steels, a quenching-unacceptable layer is not recognized at all, and an effective hardened layer depth of carburization as well as a strength of a gear core part and an impact value of a gear core part which are carburization and quenching property are equivalent to or more than those of the prior art steels and, further, since a structure is a ferrite·martensite dual-phase structure in which a ferrite area rate is 10-70% within a range of the present invention, a quenching strain amount is small as a range of 0-1%, and a dispersion within a lot is small. Fig. 3 shows a relationship between an ideal critical diameter (D_I) and a carburization and quenching strain amount of the present invention steels and the prior art steels. As apparent from the same figure, it is seen that, according to the present invention, a heat treatment strain of a gear is remarkably reduced, and a strain is 0 to around 40% of a strain of the prior art steels.

[0070] Further, as is apparent, in comparative steels No. 2-7 and 9-21, as well as prior art steels No. 1-4, chipping occurred on a tooth surface at a low torque region. To the

contrary, the present invention steels No. 1-30 have the excellent fatigue strength and dedendum strength over those of the prior art steels, and there is no quenching-unacceptable layer and, due to increase in a Si content, tempering softening resistance becomes high, chipping did not occur, and a surface pressure strength was reinforced.

[0071]

[Effect of the invention] Since the present invention is constructed as described above, an amount of a strain due to carburization and quenching treatment can be suppressed at a small value of 0-1.0 as compared with around 2.4-3.6 of the prior art steels, and a steel stock for a gear excellent in a dedendum strength can be obtained by the conventional carburization and quenching treatment, and is suitable as a gear for an automobile which is not subjected to tooth form correction, and a carburization and quenching strain amount can be reduced also in a gear for a construction machine, and an industrial machine and the like requiring tooth form correction after carburization and quenching, thus, tooth form correction is not necessary and, therefore, a low strain type carburized and quenched steel stock for a gear which can reduce a procession cost and improve productivity can be provided, and industrially many excellent effects are obtained.

[Brief explanation of the drawings]

[Fig. 1] A front view showing one example of a test piece for measuring a carburization and quenching strain amount (Navy C test piece).

[Fig. 2] A side view of Fig. 2.

[Fig. 3] A graph showing a relationship between an ideal critical diameter (D_I) and a carburization and quenching strain amount of the present invention steels and the prior art steels.

[Fig. 4] A schematic perspective explaining an interior of a tooth and a surface part of a gear.

[Fig. 5] A graph showing an example of heat treatment pattern of carburization treatment and quenching by the conventional method.

[Explanation of the symbols]

1 Navy C test piece

2 Opening part

3 Circular space

4 Tooth interior (non-carburized part)

5 Tooth surface part (carburized part)

6 Gear core part